CHAPTER 9

CULVERTS

Chapter Table of Contents (continued)

9.1 Introduction

Definition
9.1.1

A culvert is defined as the following.

- A structure which is usually designed hydraulically to take advantage of **ponding above the inlet** to increase hydraulic capacity.

A structure used to convey surface runoff **or irrigation waters** through embankments. **It may be a round pipe, box, arch, open-bottom arch or ellipse, made of concrete, steel, aluminum or high-density polyethylene.**

Purpose
9.1.2

This chapter provides design procedures for the hydraulic design of highway culverts which are based on FHWA Hydraulic Design Series Number 5 (HDS 5), Hydraulic Design of Highway Culverts, **and USBR Design of Small Canal Structures. These two references should be used in conjunction with this chapter.** This chapter also:

- presents results of culvert analysis using microcomputers which emphasizes the use of **MDT's Standard Step Program and FHWA's** HY 8 culvert analysis software, and
- provides a summary of the design philosophy contained in the AASHTO Highway Drainage Guidelines, Chapter IV.

Concepts
9.1.3

Following are discussions of concepts which are important in culvert design.

Critical Depth

Critical depth is the depth at which the specific energy of a given flow rate is at a minimum. For a given discharge and cross-section geometry there is only one critical depth. HDS 5 contains critical depth charts for different shapes.

Crown

The crown is the inside top of the culvert.

Flow Line

The flow line is the bottom of the channel, or the channel grade line. The invert of the pipe may be above or below the flow line.

Free Outlet

A free outlet has a tailwater equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.

Improved Inlet

An improved inlet has an entrance geometry which decreases the flow constriction at the inlet and thus increases the capacity of culverts. These inlets are referred to as either side- or slope-tapered (walls or bottom tapered).

Inlet Control

Inlet control occurs when the culvert barrel is capable of conveying more flow than the inlet will accept. It is a function of the headwater elevation, inlet area, inlet edge configuration and inlet shape. Factors such as roughness of the culvert, length of the culvert, and slope of the culvert do not affect the capacity of a culvert in inlet control.

Invert

The invert is the flow line of the culvert (inside bottom).

Normal Flow

Normal flow occurs in a channel reach when the discharge, velocity and depth of flow do not change throughout the reach. The water surface profile and channel bottom slope will be parallel. This type of flow will exist in a culvert operating on a steep slope provided the culvert is sufficiently long.

Outlet control

Outlet control occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. It is a function of the headwater elevation, inlet area, inlet edge configuration, inlet shape, roughness of the culvert, area and shape of the barrel, length of the culvert, slope of the culvert, and tailwater elevation.

Slope

- A steep slope **is defined as a slope** where the critical depth (d_c) is greater than the normal depth (d_n).
- Mild slope **is defined as a slope** where critical depth (d_c) is less than normal depth (d_n).

Submerged

- A submerged outlet occurs where the tailwater elevation is higher than the crown of the culvert.

A submerged inlet occurs where the headwater is greater than 1.2D.

9.1 Introduction (continued)

Symbols 9.1.4

To provide consistency within this chapter as well as throughout this manual, the following symbols will be used. These symbols were selected because of their wide use in culvert publications.

Symbol	Definition	Units
A	Area of cross section of flow	ft^2
AHW	Allowable HW	ft
B	Barrel width	ft
D	Culvert diameter or barrel height	in. or ft
d	Depth of flow	ft
d_c	Critical Depth of flow	ft
d_n	**Normal depth of flow**	**ft**
g	Acceleration due to gravity	ft/s^2
H	Sum of $H_E + H_f + H_o$	ft
H_b	Bend headloss	ft
H_E	Entrance headloss	ft
H_f	Friction headloss	ft
H_L	Total energy losses	ft
H_o	Outlet or exit headloss	ft
H_v	Velocity headloss	ft
h_o	Hydraulic grade line height above outlet invert	ft
HW	Headwater depth (subscript indicates section)	ft
K_E	Entrance loss coefficient	-
L	Length of culvert	ft
n	Manning’s roughness coefficient	-
P	Wetted perimeter	ft
Q	Discharge	cfs
R	Hydraulic radius (A/P)	ft
S	Slope of culvert	ft/ft
TW	Tailwater depth above invert of culvert	ft
V	Mean velocity of flow with barrel full	ft/s
V_d	Mean velocity in downstream channel	ft/s
V_o	Mean velocity of flow at culvert outlet	ft/s
V_u	Mean velocity in upstream channel	ft/s

9.2 Policy

Definition
9.2.1

Policy is a set of goals that establish a definite course of action or method of action and that are selected to guide and determine present and future decisions (see Policy Chapter). Policy is implemented through design criteria for making decisions (see Section 9.3).

Drainage Culverts
9.2.2

The following policies are specific to **drainage** culverts.

- **All culverts larger than minimum size (24”) shall be hydraulically designed, except for those designed using Procedure Memorandum 10 (see Appendix).**
- **The design flood selected shall be consistent with the criteria defined in Appendix A of the Hydrology Chapter.**
- **Culverts shall be aligned vertically and horizontally with the natural channel to avoid sediment build up.**
- The cost savings of multiple use (utilities, stock and wildlife passage, land access, and fish passage) shall be weighed against the advantages of separate facilities.
- Culverts shall be designed to accommodate debris **and/or ice** or proper provisions shall be made for maintenance.
- Material selection shall include consideration of service life which includes abrasion and corrosion.
- Culverts shall be located and designed to present a minimum hazard to traffic and people.
- The detail of documentation for each culvert site shall be commensurate with the risk and importance of the structure. Design data and calculations shall be assembled in an orderly fashion and retained for future reference **(see 23 CFR 650A)**.
- Where practicable, some means shall be provided for personnel and equipment access to facilitate maintenance.

Irrigation Culverts 9.2.3

The following policies are specific to **irrigation** culverts.

- **Irrigation crossings should be designed in accordance with Procedure Memorandum No. 6, in Appendix F.**
- **All irrigation culverts larger than minimum size (18") shall be hydraulically designed.**
- **Culverts shall be aligned vertically and horizontally with the irrigation canal to avoid sediment build up.**
- **Culverts shall be designed to accommodate debris and/or ice or proper provisions shall be made for maintenance.**
- **Material selection shall include consideration of service life which includes abrasion and corrosion.**
- **Culverts shall be located and designed to present a minimum hazard to traffic and people. For pipes 30-inch in diameter and smaller, the pipe shall be extended to the right-of-way line, in accordance with the MDT Road Design Manual.**
- **The detail of documentation for each culvert site shall be commensurate with the importance of the structure. Design data and calculations shall be assembled in an orderly fashion and retained for future reference (see Procedure Memorandum No. 6 in the Appendix).**
- **Where practicable, some means shall be provided for personnel and equipment access to facilitate maintenance.**

9.3 Design Criteria

Definition
9.3.1

Design criteria are the standards by which a policy is carried out or placed into action. They form the basis for the selection of the final design configuration. Listed below by categories are the design criteria which shall be considered for all culvert designs.

Site Criteria
9.3.2

Structure Type Selection

Culverts are used:

- where bridges are not hydraulically required,
- where debris and ice are tolerable, and
- where more economical than a bridge.

Advantages of a culvert include:

- **can be extended so guardrail is not required,**
- **will generally stop headcuts,**
- **are not susceptible to failure due to scour (except for open-bottom arches),**
- **stage construction could eliminate the need for a detour,**
- **require less maintenance than a bridge,**
- **could provide additional cover for fish,**
- **snow and sanding material plowed from the roadway is less likely to reach the stream.**

Disadvantages of a culvert include:

- **may hinder passage of fish if appropriate design considerations are not included,**
- **can create scour hole at outlet of pipe,**
- **may not be adequate for ice or debris,**
- **has a longer imprint on the stream reach.**

Bridges are used:

- where culverts cannot be used,
- where more economical than a culvert,
- to satisfy land use requirements,
- to mitigate environmental harm caused by a culvert,
- to avoid floodway or irrigation canal encroachments, and
- to accommodate ice and large debris.

Site Criteria (continued)

Length & Slope

The culvert length & slope shall be chosen to approximate existing topography, and to the degree practicable:

- the culvert invert shall be aligned with the channel bottom and the skew angle of the stream, and
- the culvert entrance shall match the geometry of the roadway embankment. **Maximum skew and culvert end sections shall meet the criteria in Chapter 17 of the MDT Road Design Manual.**

Ice Conditions

Floating ice conditions may be mitigated as necessary by:

- increasing the culvert height above the maximum observed ice level, or
- increasing the culvert width to encompass the channel width, or
- **where metal pipes are provided with concrete edge protection, use twice the number of anchor bolts shown on the detailed drawing.**

Sheet ice conditions may be mitigated by installation of an overflow culvert or increasing the culvert height above the maximum observed ice level.

Debris Control

Debris control shall be designed using Hydraulic Engineering Circular No. 9, "Debris-Control Structures" and shall be considered where experience or physical evidence indicates the watercourse will transport a heavy volume of controllable debris.

Design Limitations 9.3.3

Allowable Headwater

Allowable headwater is the depth of water that can be ponded at the upstream end of the culvert which will be limited by one or more of the following:

- **the headwater criteria in Appendix A of the Hydrology Chapter, for the design flow and the 100-year flow,**
- a maximum **0.5 foot** increase over the existing 100-year flood elevation in the National Flood Insurance Program mapped floodplains.

Tailwater Relationship - Channel

Evaluate the hydraulic conditions of the downstream channel to determine a tailwater depth for a range of discharges which includes the review discharge (see Channel Chapter).

9.3 Design Criteria (continued)

Design Limitations (continued)

- Calculate backwater curves at sensitive locations or use a single cross section analysis.
- Use the **average of the critical depth and the pipe diameter ($(d_c + D)/2$)** if the culvert outlet is operating with a free outfall.
- Use the headwater elevation of any nearby, downstream culvert **or control structure** if it is greater than the channel depth.

Tailwater Relationship - Confluence or Large Water Body

- Use the high water elevation that has the same frequency as the design flood if events are known to occur concurrently (statistically dependent).
- If statistically independent, evaluate the joint probability of flood magnitudes **(using Table 9-1, adopted from the August 1991 Highway Drainage Guidelines, Storm Drain Systems)** and use a likely combination resulting in the greater tailwater depth. **For example, a main stream and tributary have a drainage ratio of 100 to 1 and a 10 year design is required for the culvert. Table 9-1 indicates that:**

  1) when a 10 year flow is applied to the tributary, the high water of the main stream should be determined for a 5 year return period; and

  2) when a 10 year high water is used on the main stream, a 5 year flow should be applied to the tributary.

Table 9-1
Storm Frequencies For Coincidental Occurrence

Drainage Area Ratio	10-Year Design		100-Year Design	
	Main Stream	Tributary	Main Stream	Tributary
10,000 to 1	2	10	2	100
	10	2	100	2
1,000 to 1	2	10	10	100
	10	2	100	10
100 to 1	5	10	25	100
	10	5	100	25
10 to 1	10	10	50	100
	10	10	100	50
1 to 1	10	10	100	100
	10	10	100	100

Maximum Velocity

If the velocity at the culvert exit exceeds 10 feet/second at the 10-year return period flow, the energy shall be dissipated with:

- **a riprap apron designed in accordance with the criteria in Appendix I, or**
- channel stabilization (see Channel Chapter), or
- energy dissipation (see Energy Dissipator Chapter).

Design Limitations (continued)

Storage - Temporary or Permanent

If storage is being assumed upstream of the culvert, consideration shall be given to:

- the total area of flooding, and
- **recommending** that the storage area will remain available for the life of the culvert through the purchase of right-of-way or easement, **in areas of possible development.**

Flood Frequency

The flood frequency used to design or review the culvert shall be based on:

- **the criteria in Appendix A of the Hydrology Chapter,**
- the level of risk associated with failure of the crossing, increasing backwater, or redirection of the floodwaters, and
- location of FEMA mapped floodplains

Design Features 9.3.4

Culvert Sizes and Shape

The culvert size and shape selected shall be based on engineering and economic criteria related to site conditions.

- The following minimum sizes shall be used to avoid maintenance problems and clogging:

  24 inches for cross-drains
  18 inches for approaches and irrigation crossings.

- Land use requirements can dictate a larger or different barrel geometry than required for hydraulic considerations.
- Use arch shapes only if required by hydraulic limitations, **minimum cover requirements,** site characteristics, structural criteria **(as described in the Road Design Manual)**, or environmental criteria.
- **Shapes commonly used by MDT include round and arch pipes and rectangular concrete box.**
- **Due to special design considerations, long-span ellipses and open-bottom arches must be designed by MDT's Hydraulics Section. Open-bottom arches shall be used only after a detailed scour analysis is completed.**

Design Features (continued)

Multiple Barrels

Multiple barrel culverts shall fit within the natural dominant channel with minor widening of the channel so as to avoid conveyance loss through sediment deposition in some of the barrels. **Consideration should be given to installation of a berm around the inlet of the extra pipe(s). Where minor widening will not accommodate the multiple barrels, one pipe should be placed in the channel, with additional pipes placed at a higher elevation (typically the bankfull elevation).** Multiple culverts are to be avoided where:

- the approach flow is high velocity, particularly if supercritical, (These sites require either a single barrel or special inlet treatment to avoid adverse hydraulic jump effects.)
- irrigation canals or ditches are present (unless approved by the canal or ditch owner), and
- fish passage is required unless special treatment is provided to insure adequate water depth at low flows (commonly one barrel is lowered).

Material Selection

The material selected shall be based on **MDT's Culvert Service Life Guidelines (Appendix E) and MDT's optional pipe guidelines (section 5.3 of the Road Design Manual). Reinforced concrete pipe shall be the basic bid, where RCP is an acceptable option.**

Other factors to be considered in material selection include:

- **bed load**,
- structural strength,
- hydraulic roughness,
- **in-place foundation conditions,**
- abrasion and corrosion resistance, and
- water tightness requirements.

Culvert Skew

The culvert skew shall not exceed 35 degrees as measured from a line perpendicular to the roadway centerline without the approval of **MDT's Hydraulics Section**. **A more detailed description of the issues relating to culvert skew is presented in Section 17.1(14) of the MDT Road Design Manual.**

End Treatment (Inlet or Outlet)

The culvert inlet type shall be selected from the following list **(and in accordance with the Road Design Manual)** based on the considerations given and the inlet coefficient, K_E. A table of recommended values of K_E is included in Table 9-2. Consideration shall also be given to safety since some end treatments can be hazardous to errant vehicles.

Design Features (continued)

Projecting Inlets or Outlets

- Extend **2 feet** beyond the embankment of the roadway, **for fill slopes 2:1 or steeper.**
- Are susceptible to damage during roadway maintenance and automobile accidents.
- Have poor hydraulic efficiency for thin materials (K_E = 0.9).

Bevels with Concrete Edge Protection

- Increase the efficiency of metal pipe.
- Provide embankment stability.
- Provide embankment erosion protection.
- Provide protection from buoyancy.
- Reduce maintenance damage.
- **Round metal pipes larger than 48” shall have step bevel ends.**
- **Arch metal pipes larger than equivalent 48” shall have bevel ends.**

Improved Inlets

- May be considered for culverts which will operate in inlet control.
- Can increase the hydraulic performance of the culvert, but may also add to the total culvert cost. Therefore, they should only be used if practicable.

Commercial End Sections

- Are available for both corrugated metal and concrete pipe.
- They retard embankment erosion and incur less damage from maintenance.
- May improve projecting metal pipe entrances by increasing hydraulic efficiency, reducing the accident hazard, and improving their appearance.
- **Shall be used for metal pipes up to 48” and concrete pipes up to 84”.**

Wingwalls with headwalls

- Are used to retain the roadway embankment to avoid a projecting culvert barrel.
- Are used where the side slopes of the channel are unstable.
- Are used where the culvert is skewed to the normal channel flow.
- Can affect hydraulic efficiency if the flare angle is < 30 degrees or > 60 degrees.
- **Can be used to transition from a “wide” channel to a “narrow” culvert.**

TABLE 9-2
ENTRANCE LOSS COEFFICIENTS
Outlet Control, Full or Partly Full

Type of Structure and Design of Entrance	Coefficient K_E
For FHWA's HY 8 Program	
Pipe, Concrete	
Square edge with headwall (also used for FETS)	0.5
Grooved end projection	0.2
Grooved end in headwall	0.2
Beveled Edge (1:1 or 1.5:1) (see HDS 5 for definition sketches; not generally used by MDT)	0.2
Side- or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal	
Thin edge projecting	0.9
Mitered to conform to slope (also used for Bevel or Step Bevel Ends)	0.7
Square edge with headwall (also used for FETS)	0.5
Beveled edge (1:1 or 1.5:1) (see HDS 5 for definition sketches; not generally used by MDT)	0.2
For MDT's Standard Step Program	
90 Degree headwall with spill cones	
Square edge (RCP) (also used for FETS)	0.5
Corrugated metal (also used for FETS)	0.5
Groove end (RCP)	0.2
All bevels (see HDS 5 for definition sketches; not generally used by MDT)	0.2
Mitered to embankment slope	
Metal Step Bevel Ends	0.7
Metal Bevel Ends	0.7
Projecting	
Corrugated metal	0.9
Concrete	0.5
Concrete with groove end	0.2

Design Features (continued)

Aprons

- **Will be considered as a transition for depressed pipes (pipes with the invert set below the channel bottom).**
- **Will generally be constructed using riprap or gabions.**
- **Should be placed on a slope of 6:1 to 10:1, from the invert of the pipe to the bottom of the channel.**

<u>Safety Considerations</u>

Traffic shall be protected from culvert ends as follows.

- Small culverts (**48”** in diameter or less) shall use a **commercial** end section **(FETS for cross-drains, RACETS for approach pipes in the clear zone), and**

- Culverts greater than **36**” in diameter shall receive one of the following treatments.

    a. Be extended to the appropriate “clear zone” distance per AASHTO Roadside Design Guide.

    b. Shielded with a traffic barrier if the culvert is very large, cannot be extended, has a channel which cannot be safely traversed by a vehicle, or has a significant flooding hazard with a grate.

<u>Performance Curves</u>

Performance curves **or tables** shall be developed for all culverts **larger than minimum size** for evaluating the hydraulic capacity of a culvert for various headwaters, outlet velocities, and scour depths. These curves will display the consequence of high flow rates at the site and provide a basis for evaluating flood hazards. **Analyze one size larger and one size smaller than the recommended size.**

Irrigation Facilities 9.3.5

Several methods of determining a design flow for an irrigation crossing can be used. The methods listed below are in order of preference.

- **Data submitted from owner**
- **Capacity of existing system (based on a water surface profile model)**
- **Water rights data, available from Montana Department of Natural Resources**
- **One cfs. for every 20 acres irrigated (rough “rule-of-thumb”)**

For design of a new irrigation crossing, the first step should generally be to model the existing crossing using MDT’s Standard Step Program. The model can be calibrated using the water surface elevations and flows at the time of the survey.

Irrigation facilities shall be designed to accommodate the irrigation and flood waters using the criteria below which gives the largest culvert size:

- constrain the headwater within the existing canal or ditch banks unless provision is made for overflow during high flows,
- provide freeboard to accommodate expected debris,
- **maximum backwater of 0.3 foot, subject to approval of ditch owner; if**

existing structure creates more than 0.3 foot of backwater, the new structure should match the existing backwater (unless operational problems are evident),

- no increase in the velocity beyond what the unprotected ditch material or protection will sustain,
- avoid a flood hazard from a canal or ditch failure,
- provide a hypothetical canal or ditch width capable of delivering the irrigation and flood waters at its existing operating depth, and
- provide for known winter ice accumulation problems.

In addition, several other factors should be considered:

- **The location of existing turnouts and check structures may limit the allowable change in backwater.**
- **The pipe width should be close to the water surface width. Use of arch pipes or concrete boxes will often help to achieve this.**
- **Transition structures can be used to transition between a wide canal and a narrow pipe.**
- **Depressing the pipe below the channel bottom can increase the flow capacity. A transition from the canal bottom to the pipe invert may be necessary. The transition can be constructed from earth, gravel or concrete, depending on the velocity in the transition section.**
- **When a siphon is used, the maximum permissible head on standard siphon pipe is 20 feet. When the head exceeds this value, other pipe and joint options must be used.**
- **When an irrigation pipeline is parallel to the roadway, a leakage specification for this pipe should be used.**
- **Design criteria for relocation of irrigation canals is included in the Channels Chapter.**

Selection of appropriate end sections is often an issue in design of irrigation pipes. The following guidelines should be considered in selecting an appropriate end section.

- **For small irrigation ditches, a square end pipe can be used. A commercial end section (FETS) is usually too wide to fit the ditch cross-section. Small irrigation pipes are typically extended to the Right-of-Way line, so the pipe ends are beyond the clear zone.**
- **When the culvert width approximately matches the canal width (even for larger canals), a square end can be used. In these situations, a cutoff wall should be considered, with the height of the wall 6 inches above the design flow depth. For concrete boxes, the modified "x" dimension for a higher cutoff wall can be achieved by eliminating some sections of the tapered end section.**
- **When the canal width is larger than the culvert width, a FETS can be used as a transition. A FETS is also useful where a trash rack is required.**
- **When the canal width is much larger than the culvert width, MDT's**

standard concrete transition structure should be considered. These structures are also typically used in locations where there are vertical changes, and for siphons.

- **Consider use of USBR transitions (described in USBR Design of Small Canal Structures) only where maximum efficiency is required.**

Unless **the narrative irrigation study by the Right-of-Way Bureau, or Right-of-Way negotiations indicate otherwise**, an irrigation structure shall be required even if the irrigation canal or ditch is no longer used. **The Right-of-Way Bureau can be requested to pursue abandonment of such canals.** The canal or ditch owner shall approve the use of multiple barrel culverts. Provision should be made to accommodate any water escaping the ditch so as to avoid a flood hazard.

During the design, MDT is sometimes asked to increase the size of an irrigation pipe due to plans to expand the ditch capacity. The larger capacity should be accommodated if the design plans for the ditch expansion are complete, and the funding for the construction is in place.

Related Designs
9.3.6

Buoyancy Protection

Buoyancy is more serious with steepness of the culvert slope, depth of the potential headwater (debris blockage may increase), flatness of the upstream fill slope, height of the fill, large culvert skews, or mitered ends. **Cutoff walls, concrete edge protection, and limiting head water,** or other means of anchoring to provide buoyancy protection shall be considered for all flexible culverts **larger than 48"**.

Outlet Protection (See Energy Dissipator Chapter)

In general scour holes at culvert outlets provide efficient energy dissipaters. **A field review of the existing culvert should be made to determine the possible need for outlet aprons (see Appendix I for dimensional criteria). Where there is an existing scour hole, it should not be filled in, but lined with appropriate sized riprap if continued scour is a concern.**

Relief Opening

Where multiple use culverts or culverts serving as relief openings have their outlet set above the normal stream flow line, special precautions shall be required to avoid headcuts that would undermine the culvert outlet.

Land Use Culverts

Consideration shall be given to combining drainage culverts with other land use requirements (stockpasses, vehicle underpasses and pedestrian underpasses) necessitating passage under a highway. The following should be considered:

- during the selected design flood the land use is temporarily forfeited, but available during lesser floods,
- two or more barrels are required with one situated so as to be dry during low flows,
- the outlet of the higher land use barrel must be protected from headcutting,
- the size of pipe for land use functions shall be determined by the Right-of-Way Bureau.

Erosion and Sediment Control

In perennial streams where there is significant bedload, sediment control can be an issue. In an attempt to insure sediment passage, the flow with a return period of 1.5 years should be accommodated with minimal increase in water depth. For perennial streams with bedload, consideration should be given to setting the pipe invert below the channel flow line. Temporary erosion control is the responsibility of Environmental Services. Guidelines are published in MDT's Erosion Control Manual.

Environmental Considerations and Fishery Protection

Care must be exercised in selecting the location of the culvert site to control erosion, sedimentation and debris. Select a site that will permit the culvert to be constructed and will limit the impact on the stream or wetlands. **Where wetlands upstream from the culvert could be drained by installing a culvert at the channel invert, the culvert should not be elevated above the channel invert, but a berm may be constructed upstream from the pipe inlet.** For more information, see the Environment Chapter.

9.4 Design Philosophy

Overview
9.4.1

The design of a culvert system for a highway crossing of a floodplain involves using information from the following chapters in this manual (policy, documentation, surveys, hydrology, channels, storm drains, erosion and sediment control, and environment). Each of these should be consulted as appropriate. The discussion in this section is focused on alternative analysis and design methods.

Alternative Analysis
9.4.2

Culvert alternatives shall be selected which satisfy:

- topography, and
- design policies and criteria.

Alternatives shall be analyzed for:

- hydraulic efficiency,
- risk and cost, and
- environmental impact,

A minimum of three alternatives shall be analyzed, including the selected size, and pipes one size larger and one size smaller. Select an alternative which best integrates engineering, economic and political considerations. The chosen culvert shall meet the selected structural, hydraulic **and pipe life** criteria and shall be based on:

- construction and maintenance costs,
- risk of failure or property damage,
- traffic safety,
- environmental or aesthetic considerations,
- political or nuisance considerations, and
- land use requirements.

Design Methods
9.4.3

Hydrology Methods

Constant Discharge

- Is assumed for most culvert designs.
- Is usually the peak discharge.
- Will yield a conservatively sized structure where temporary storage is available, but not **considered**.

Hydrograph & Routing

- Storage capacity behind a highway embankment attenuates a flood hydrograph and reduces the peak discharge.
- Significant storage will reduce the required culvert size.
- Is checked by routing the design hydrographs through the culvert site to determine the outflow hydrograph and stage (backwater) behind the culvert.
- Procedures are in **Appendix G** and HDS 5, Section V.

9.4 Design Philosophy (continued)

Design Methods (continued)

Computer Software

MDT Standard Step Program

- **Water surface profile program.**
- **Uses standard step backwater analysis for upstream and downstream channels.**
- **Used for crossings in series.**
- **Used to determine backwater impacts of placing pipes (including siphons) in irrigation ditches.**
- **Used for buried pipes (where the bottom of the pipe is filled with sediment).**

HY 8 (FHWA Culvert Analysis Software)

- Can compute tailwater, improved inlets, road overtopping, hydrographs, routing, and multiple independent barrels.
- Develops and plots tailwater rating curves.
- Develops and plots performance curves.
- Is documented in HYDRAIN Users Manual and HY 8 Applications Guide.
- **Pipe slope must be positive, and should be greater than 0.1%.**
- **Flow range specified should not include overtopping. If flow range includes overtopping, calculation of overtopping may be incorrect.**
- **Default values of Manning's n value are incorrect for round metal pipes with 3" x 1" or 5" x 1" corrugations (these corrugations are typically used for pipes larger than 48").**
- **Default values of Manning's n value are incorrect for round structural plate steel pipes. These pipes generally have 6" x 2" corrugations, and HY 8 assigns a Manning's n value of 0.024 to them, rather than 0.033 to 0.034.**
- **When multiple independent pipes are used, computed flow split should be reviewed carefully.**

9.5 Design Procedure

The following design procedure provides an **outline** for designing culverts for a constant discharge, considering inlet and outlet control. The procedure does not address the affect of storage which is discussed in the Storage Chapter and **Appendix G**.

- The designer should be familiar with **FHWA HDS 5, Hydraulic Design of Highway Culverts,** before using these procedures.
- *Following the design method without an understanding of culvert hydraulics can result in an inadequate, unsafe, or costly structure.*
- **A project summary form has been provided in Appendix D to guide the user. It contains spaces for station, overtopping elevation and location, design flow, 100-year flow (for drainages), existing structure size, capacity and adequacy, and selected structure size, capacity and head-water elevation. This form should be included in the Hydraulics Report. In addition to the selected structure size and capacity, the capacity and headwater elevation for structures one size smaller and one size larger should be included.**

Step 1 <u>Assemble Site Data And Project File</u>

a. See Data Chapter - The minimum data are:

- USGS, site, and location maps,
- embankment cross section,
- roadway profile,
- **overtopping elevation and location (existing and new)**
- **location and elevation of any upstream buildings that are below existing or new roadway grades.**
- **MDT Drainage Structure Flood Summaries**

b. Studies by other agencies including:

- small dams - NRCS (formerly SCS), **DNRC**
- canals - NRCS, USBR,
- floodplain - NRCS, COE, FEMA, USGS,
- **flood control - COE (dikes), NRCS.**

c. Environmental constraints including:

- commitments contained in review documents, and
- **fish passage**.

d. Design criteria

- review Section 9.3 for applicable criteria, and
- **determine potential risk at the site (see Hydrology Chapter, Appendix A, on risk assessment).**

Step 2

Determine Hydrology

See Hydrology Chapter.

Step 3

Select Design Alternative

a. See Section 9.3.4 Design Features.

b. Choose culvert material, shape, size, and entrance type.

c. Both concrete (basic bid) and metal pipe will generally be analyzed. Selection of pipe material will meet MDT's Optional Pipe Policy.

Step 4

Compute Hydraulics of Design Options

a. Based on site geometry, determine pipe invert elevations, pipe length and downstream channel shape (for tailwater computations).

b. Using MDT's Standard Step Program, or FHWA's HY 8 Program, determine the headwater elevations for the design flow and the 100-year flow, and the magnitude of the overtopping flow, for the selected pipe size.

c. Compare headwater to allowable headwater criteria in Appendix A of the Hydrology Chapter. Roadway overtopping should not occur at flows less than or equal to the design flow.

d. Computations should generally be completed for concrete and metal pipe, and for pipes one size smaller and one size larger than the selected pipe size.

Step 5

Compute Culvert Service Life

Using the information in Appendix E, compute the culvert service life based on the soil samples obtained.

9.6 HY 8 Solution

Overview
9.6.1

Culvert hydraulic analysis can be accomplished with the aid of the HYDRAIN software. The following example has been produced using the HY 8 Culvert Analysis Microcomputer Program Version **4.0**. The screens may vary **depending on the version of HY 8 being used.**

Data Input
9.6.2

After creating a file, the user will be prompted for the discharge range, site data and culvert shape, size, material and inlet type. **The discharge range for this example will be from 1040 to 2040 cfs, with a design flow of 1420 cfs, and a 100-year flow rate of 2040 cfs. The site data is entered by providing culvert invert data. If embankment data points are input, the program will determine the culvert length.**

Culvert Data

Numerous trials were completed for this example. This example will show only the selected option, but a thorough hydraulic analysis should always include several options. A single pipe was not adequate to carry the design flow without overtopping, therefore multiple pipes were analyzed. The invert of the larger pipe was set at the channel bottom, and the invert of the smaller pipe was set at the elevation of the adjacent floodplain. The span of the larger pipe equaled or exceeded the width of the active channel, so it was not reasonable to set both pipes at the same elevation, and build a low water berm around one of them. The larger pipe is a 16'3" x 12'4" SSPPA, and the smaller pipe is a 12'4" x 7'9" SSPPA. For each pipe, the end section will be a beveled end, which should be modeled as a conventional inlet, mitered to conform to the slope. As each group of data is entered the user is allowed to edit any incorrect entries. The screen that summarizes the culvert information is shown in Figure 9-1.

Channel Data

Next the program will prompt for data pertaining to the channel so that tailwater elevations can be determined. The channel is irregularly shaped and can be described by the 10 coordinates listed in Figure 9-2. After opening the irregular channel file the user will be prompted for channel slope (.0006), number of cross-section coordinates (10) and subchannel option. The subchannel option in this case would be option (2), left and right overbanks (n =.06) and main channel (n =.03).

```
Culvert File:  SageCr            FHWA CULVERT ANALYSIS           Date: 02-14-1996
Tailwater File:  SageCr            HY8, Version 4.0              Culvert No. 1 of 2

        Item                                Selected Culvert
        <1> Barrel Shape:                   Pipe-Arch
        <2> Barrel Size:                    Span  =  195.4 In   Rise  =  130.2 In
        <3> Barrel Material:                Steel Structural Plate
                                            Corner Radii =  31
        <4> Manning's N:                    .034
        <5> Inlet Type:                     Conventional
        <6> Inlet Edge and Wall:            Mitered
        <7> Inlet Depression:               None

        <Number>          To Edit Item
        <Enter>           To Continue Data Listing

1-Help   2-Progr   3   4   5-End   6   7-Edit   8   9-DOS   10
```

Figure 9-1
Culvert Data Listing

```
                         IRREGULAR CHANNEL CROSS-SECTION
          Cross-Section               X                   Y
          Coord. Number              (Ft)                (Ft)

                1                    0.00              4409.40
                2                    0.00              4393.50
                3                   30.00              4393.50
                4                   40.00              4391.50
                5                   45.00              4390.50
                6                   55.00              4390.50
                7                   60.00              4391.50
                8                   70.00              4393.50
                9                  100.00              4393.50
               10                  100.00              4409.40

        <Number>            To Edit Coordinates  *
        <1>  <D>            To Insert or Delete
        <Enter>             To Continue
        <P>                 To Plot Cross-Section

1-Help   2-Progr   3   4   5-End   6   7-Edit   8   9-DOS   10
```

Figure 9-2
Channel Coordinates

Data Input
(continued)

The next prompt, for channel boundaries, refers to the number of the coordinate pair defining the left subchannel boundary and the number of the coordinate pair defining the right subchannel boundary. The boundaries for this example are the 4th and 7th coordinates. After this is input, the program prompts for channel coordinates. Once these are entered, pressing (P) will cause the computer to display the channel cross-section. The user can easily identify any input errors by glancing at the plot. To return to the data input screens, press any key. If data are correct press (return). The roughness data for the main channel and overbanks can then be entered.

Rating Curve
9.6.3

The program now has enough information to develop a uniform flow rating curve for the channel and provide the user with a list of options. Selecting option (T) on the Irregular Channel Data Menu will make the program compute the rating curve data and display the following table. Selecting option (I) will permit the user to interpolate data between calculated points.

Culvert File: SageCr | FHWA CULVERT ANALYSIS | Date: 02-14-1996
Tailwater File: SageCr | HY8, Version 4.0 | Culvert No. 1 Of 2

Irregular Channel File: SageCr

No.	Flow(Cfs)	T.W.E. (Ft)	Depth (Ft)	Vel. (Fps)	Shear (Psf)
1	1040.00	497.37	7.17	4.25	0.25
2	1140.00	4397.66	7.46	4.37	0.26
3	1240.00	4397.95	7.75	4.49	0.27
4	1340.00	4398.23	8.03	4.61	0.28
5	1420.00	4398.45	8.25	4.70	0.28
6	1540.00	4398.77	8.57	4.83	0.30
7	1640.00	4399.03	8.83	4.9.	0.31
8	1740.00	4399.28	9.08	5.03	0.32
9	1840.00	4399.53	9.33	5.13	0.33
10	1940.00	4399.77	9.57	5.22	0.34
11	2040.00	4400.01	9.81	5.32	0.34

Press:
<D> For Data
<P> To Plot Rating Curve
<Esc> For Channel Shape Menu
<Enter> To Continue

1–Help 2–Progr 3 4 5–End 6 7–Edit 8 9–DOS 10

Figure 9-3
Tailwater Data

9.6 HY 8 Solution (continued)

Rating Curve (continued)

The Tailwater Rating Curve Table consists of tailwater elevation (T.W.E.) at normal depth, natural channel velocity (Vel.) in feet per second, and the shear stress in pounds per square foot at the bottom of the channel for various flow rates. **At the design flow rate of 1420 cfs, the tailwater elevation will be 4398.45 feet. The channel velocity will be 4.70 ft/s, and the shear will be 0.28 psf.** This information will be useful in the design of channel linings if they are needed. Entering (P) will cause the computer to display the rating curve for the channel. This curve, shown on below, is a plot of tailwater elevation vs. flow rate at the exit of the culvert.

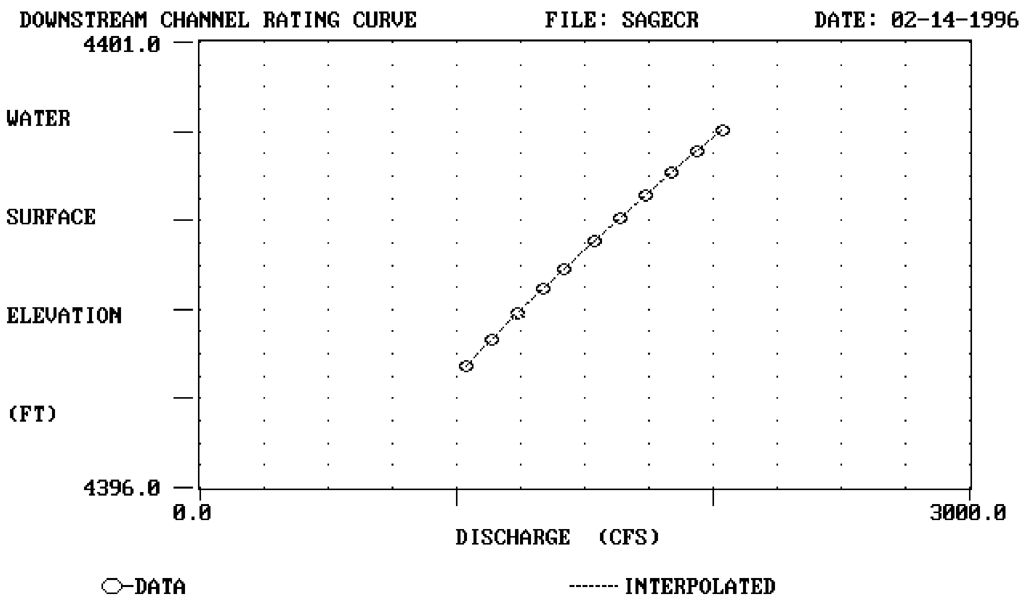


Figure 9-4
Downstream Channel Rating Curve

Roadway Data 9.6.4

The next prompts are for the roadway profile, so that an overtopping analysis can be performed. Referring to the problem statement, the roadway profile is a sag vertical curve, which will require nine coordinates to define. Once these coordinates are input, the profile will be displayed when (P) is entered. The other data required for overtopping analysis are roadway surface or weir coefficient and the embankment top width. **For this example, the roadway is paved with an embankment width of 28 feet.**

9.6 HY 8 Solution (continued)

Data Summary 9.6.5

All the data has now been entered and the summary table is displayed in Figure 9-5. At this point any of the data can be changed or the user can continue by pressing (Return), which will bring up the Culvert Program Options Menu.

Culvert File: Sagecr | FHWA CULVERT ANALYSIS | Date: 02-14-1996
Tailwater File: Sagecr | HY8, VERSION 4.0 | Culvert No. 1 of 2

SUMMARY TABLE

CULV No.	<S> Site Data			<C> Culvert Shape, Material, Inlet				
	Inlet Elev. (FT)	Outlet Elev. (Ft)	Culvert Length (Ft)	Barrels Shape Material	Span (Ft)	Rise (Ft)	Manning n	Inlet Type
1	4390.60	4390.20	146.00	1 – CSPA	16.28	10.85	.034	Conventional
2	4392.60	4392.20	146.00	1 – CSPA	12.32	7.75	.033	Conventional
3								
4								
5								
6								

Press To Review	Press To
<C> Culvert Data	<E> Edit Culvert Size
<D> Discharge Data	<M> Minimize Culvert Span
<R> Roadway Data	<A> Add or Delete Culverts
<S> Site Data	<N> Edit Number of Barrels
<T> Tailwater Rating Curve	

<Enter> To Continue

1-Help 2-Progr 3 4 5-End 6 7-Edit 8 9-DOS 10

Figure 9-5
Data Summary

Minimize Culvert 9.6.6

This feature, “Minimize Culvert Size” is intended to allow the designer to use HY 8 as a tool to perform culvert design for circular, box, elliptical, and arch shape culverts based on a user’s defined allowable headwater elevation. This feature can be activated by selecting letter “M”. Once this letter is selected it enables the user to input the allowable headwater elevation. That elevation will be the basis for adjusting the user’s defined culvert size for the design discharge. The program will adjust the culvert span by increasing or decreasing by 0.5 foot increments. It will compute the headwater elevation for the span, and compare it with the user’s defined allowable headwater. If the computed headwater elevation is lower than or equal to the defined allowable headwater elevation the minimization routine will stop, and the adjusted culvert can be used for the remainder of the program.

This feature proves to be a time saver for designers because it **allows the first trial to be close to the selected size. It will still be necessary to evaluate other sizes and pipe materials, and possibly other shapes, in order to determine the optimum pipe selection.**

Performance Curve
9.6.7

At this point the data file can be saved or renamed by selecting option (S). The culvert performance curve table can be obtained by selecting option (N). If (N) is selected before (S) and an error occurs, the file can be retrieved by loading "current". When option (N) is selected, the program will compute the performance curve table without considering overtopping in the analysis. To determine the amount of overtopping and the actual headwater, press (return), and then select (O) for overtopping. A Summary of Culvert Flows will appear on the screen, as shown in figure 9-6.

File: SageCr — SUMMARY OF CULVERT FLOWS (CFS) — Date: 03-07-1996

Elev (Ft)	Total	1	2	3	4	5	6	Roadway	Iter
4399.01	1040	674	366	0	0	0	0	0	3
4399.42	1140	730	408	0	0	0	0	0	4
4399.61	1240	834	427	0	0	0	0	0	13
4400.01	1340	902	442	0	0	0	0	0	3
4400.44	1420	954	467	0	0	0	0	0	4
4401.11	1540	1034	506	0	0	0	0	0	3
4401.68	1640	1102	539	0	0	0	0	0	3
4402.27	1740	1169	572	0	0	0	0	0	3
4402.85	1840	1234	603	0	0	0	0	0	3
4403.35	1940	1280	626	0	0	0	0	31	6
4403.60	2040	1282	627	0	0	0	0	118	5
4403.00	1935	1340	595	0	0	0	0	0	

Press:
<P> To Plot Total Rating Curve
<T> To Display Table For Each Culvert
<E> To Display Error Table
<R> To Print Report
<H> To Return To Headwater Table
<Enter> To Return To Option Menu

1-Help 2-Progr 3-Time 4 5-End 6 7 8 9-DOS 10

Figure 9-6
Summary of Culvert Flows

This computation table is used when overtopping and/or multiple culvert barrels are used. It shows the headwater, total flow rate, the flow through each barrel and overtopping flow, and the number of iterations it took to balance the flows. From this information a total (culvert and overtopping) performance curve, Figure 9-7, can be obtained by selecting option (1). This curve is a plot of the headwater elevation vs. the total flow rate which indicates how the culvert or group of culverts will perform over the selected range of discharges. It is especially useful for comparing the effects of various combinations of culverts.

9.6 HY 8 Solution (continued)

Performance Curve (continued)

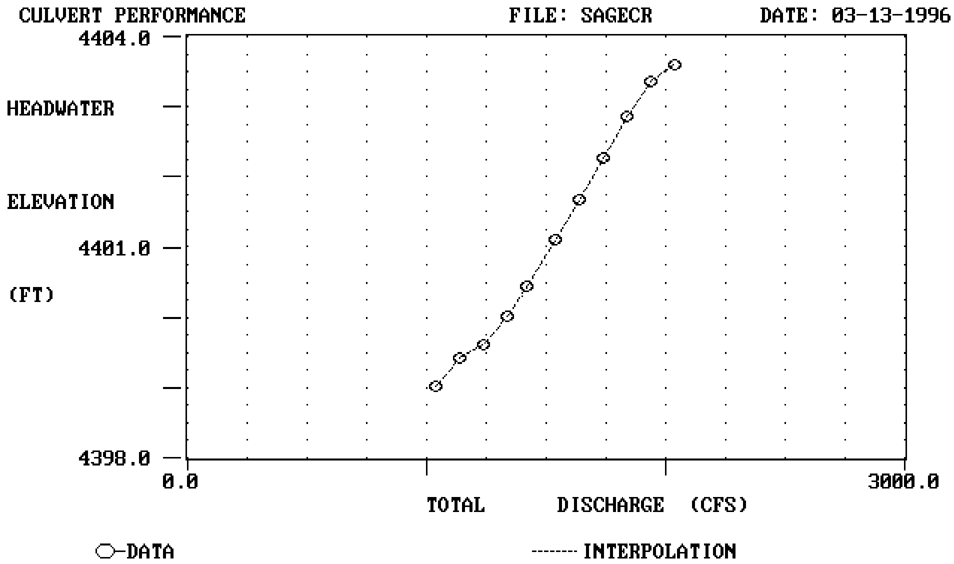


Figure 9-7
Total Performance Curve

Review 9.6.8

From the Summary table, when the total flow is 1420 cfs, 954 cfs passes through the larger culvert and 467 cfs flows through the smaller culvert. The headwater elevation will be 4400.44 feet. Referring back to the performance curve data, the outlet velocity for the larger pipe at 954 cfs is 6.90 ft/s, and for the smaller pipe the outlet velocity is 6.30 ft/s at 467 cfs. The tailwater rating curve generated previously indicates that the natural channel velocity at 1420 cfs is 4.70 ft/s, so some increase in velocity will occur.

When overtopping occurs, the performance of the culvert will differ from that without overtopping. By selecting option (2), the culvert performance data can be obtained. The user also has the option to plot these data.

9.7 Standard Step Solution

Introduction 9.7.1

Culvert hydraulic analysis can be accomplished using the Standard Step program developed by K.C. Yahvah of MDT's Hydraulic Section. This program is typically used for design of irrigation structures. It is also used for design of drainage structures with the following special conditions:

- **when the bottom of the pipe is filled in with sediment (for example, when baffles are installed for fish passage),**
- **when pipes are in series, and the backwater from one pipe influences the tailwater for the second pipe, and**
- **in delineated floodplains, where water surface elevations are important at a location other than the upstream end of the pipe.**

The following example has been produced using the MDT Standard Step program. The example is for an existing irrigation ditch crossing with a design flow of 40 cfs. The existing structure is a 32 foot long double concrete box, with a total span of 12 feet, and a rise of 25 inches. The existing box has an adverse slope of 0.94%, with the inlet 0.3 foot lower than the outlet. MDT's Standard Step program is capable of modeling an adverse slope, but FHWA's HY 8 program is not. The starting water surface slope, determined from a survey of the water surface elevations, is 0.0015 ft./ft.

Data Input 9.7.2

The most important data input is the starting water surface elevation or slope. The best source of the starting water surface slope for an irrigation canal is a survey of the water surface elevations when the canal is flowing full. When good information on the water surface slope is not available, it is important to start the water surface profile model far enough downstream that the profile converges downstream from the culvert. For nearly flat irrigation canals, this can be in excess of 1000 feet downstream.

Main Menu

The first input screen (the main menu) allows for three title lines, and requires input of design flow(s) and starting water surface elevation or slope (values less than 1 are assumed to be slopes). Figure 9-8 shows how the main menu screen appears after input of the data.

Cross-section data

The next step is to input the channel cross-section data. A minimum of one cross-section downstream from the pipe, and one cross-section upstream from the pipe are required. The downstream starting point should be far enough from the downstream end of the pipe that the model adequately represents the tailwater condition. The advantage to using this program is that additional cross-sections, downstream and/or upstream, can be used to determine water surface elevations in the vicinity of the crossing.

9.7 Standard Step Solution (continued)

Data Input (continued)

```
                         STANDARD STEP
(0)        or Enter -- START
(1)        T1 Big Timber North  F 45-1(8)0
(2)        T2 Station 177+83
(3)        T3 Existing Box
(F)        Flows  40
(E)        Starting Elevations   .0015
(X)        X-Section Data
(S)        Save Data
(C)        Convert to Metric
(P)        Pipe Data
(H)        Hec2 Slope Calculations
(W)        Edit Data File With Word Processor
(L)        Load New File
(Q)        Quit

                       Select Item To Edit

Path: S:\Billings\Step\          Input: Btn177          Output:Btn177.Out
```

Figure 9-8
Main Menu

A maximum of 50 cross-sections, with 50 points per cross-section, can be accommodated. Cross-sections should be input starting at the downstream end of the channel, progressing upstream, for subcritical flow. All cross-sections should be input starting with the left bank, looking downstream. The data required for each cross-section includes:

- **a section name (5 character maximum),**
- **a section reference distance (distance to a common point for all sections, e.g., distance from the downstream face of the culvert),**
- **the number of points in the cross-section,**
- **a constant value that can be added to or subtracted from each elevation,**
- **the x value for each data point**
- **the y value for each data point**
- **the Manning's n value between this data point and the next data point.**
- **the contraction and expansion coefficients between this cross-section and the previous cross-section**

The input data screen is shown in Figure 9-9.

Data Input (continued)

(N) Section 2 Name 17600 (R) Section Reference Distance -260
(P) No. of Pts. (0 To Repeat Previous X-Sec or Name of X-Sec To Copy) 7
(A) Amount Added To or Subtracted From Elevations 0

X	Y	N	X	Y	N	X	Y	N
0.0	4206.3	.0300						
4.3	4204.9	.0300						
5.2	4203.0	.0300						
10.4	4202.6	.0300						
15.6	4203.6	.0300						
17.3	4204.7	.0300						
26.0	4205.3	.0300						

(C) Contraction Coef .3 Expansion Coef .5
(Esc) Return To Previous Menu (I) Insert (D) Delete (X) Copy Above Value

Figure 9-9
Cross-Section Data

Pipe Data

The first pipe encountered starting from the downstream end of the channel is pipe number 1. Upstream pipes can be added by entering the next pipe number (such as 2) for "Select pipe or item to edit". The data required for each pipe includes:

- **Length of pipe**
- **Outlet flowline elevation (may not be equal to the pipe invert)**
- **Inlet flowline elevation (does not need to be higher than outlet flowline)**
- **Manning's n value for the pipe**
- **The number of channel sections that are downstream from the pipe**
- **The depth of fill in the pipe (if an existing pipe has sediment in it, or a new pipe is expected to have sediment accumulate, due to baffles, setting the pipe below the channel bottom, etc.)**
- **The Manning's n value of the fill material in the pipe**
- **The pipe size - when selecting this variable, a menu will allow a choice of Arch (for CMPA), Circular, Ellipse, RCPA, Box (for concrete boxes) and Siphon. Each of these choices will lead to another menu for selection of standard pipe sizes. After selection of a pipe size, there will be a menu for selection of inlet type. Standard Flared End Terminal Sections for metal and concrete pipe have the same coefficients as a 90 degree headwall with a square edge.**

The input data screen is shown in Figure 9-10.

Data Input (continued)

PIPE DATA
Pipe Number 1

(L) Length 32
(O) Outlet Flowline Elevation 4203
(I) Inlet Flowline Elevation or Slope -.0094 4202.7
(N) N Value .015
(D) Section No. Downstream From Pipe 2
(C) Inlet & Outlet Pipe Loss Coef .5 .7
(F) Depth of Fill (Ft) 0
(M) N Value of Fill 0
(S) Pipe Size 12 X 2.083 Box
(P) Number of Pipes 1
(R) Pipe Outlet Reference Distance 0

Select Pipe or Item To Edit

Figure 9-10
Pipe Data

Output
9.7.3

The beginning of the output from this program includes the date and time the output file was generated, the title lines that were input, the file name, pipe size (in inches), pipe length (in feet), the Manning's n value, the number of pipes, and the entrance and exit coefficients. The main part of the output includes a table of parameters for each cross-section. Following this table of parameters is a listing of the cross-section data used. The output data printout is shown below.

MONTANA DEPARTMENT OF TRANSPORTATION
Hydraulics Section
Water Surface Profile

09-25-1995 08:08:17
Big Timber North F 45-1(8)0
Station 177+83
Existing Box
File: S:\Billings\Step\Btn177
Hec2 Slope Calculations

Pipe No.	Pipe Size	Length	N	No of Pipes	Fill	N of Fill	Area of Fill	Coef
1	144 x 25	32.0	.015	1	0.00	.000	0.00	0.5 0.7 Box

Starting Slope .0015
Q = 40

Sec Name	Depth	Stage	Top Width	Area	R	K	Energy Coef	Chan Vel	Egl	Slope	Ref Dist	Hf	He	Loss Coef	Flow Line	Crit Depth
17500	2.04	4204.54	10.7	16.9	1.38	1034	1.00	2.37	4204.63	0.0015	-360.0	0.000	0.000	0.00	4202.50	0.00
17600	2.10	4204.70	12.9	19.8	1.37	1209	1.00	2.02	4204.76	0.0011	-260.0	0.127	0.007	0.30	4202.60	0.00
Pipe1	1.82	4204.82	12.0	21.9	1.40	2710	1.00	1.83	4204.88	0.0002	0.0	0.108	0.006	0.50	4203.00	0.70
Pipe1	1.84	4204.82	12.0	22.1	1.41	2755	1.00	1.81	4204.87	0.0002	2.1	0.000	0.000	0.20	4202.98	0.70
The Pipe Is Full --- H=HL+HO-LSO																
Pipe1	2.01	4204.71	12.0	25.0	0.89	2282	1.00	1.60	4204.75	0.0003	32.0	0.006	0.000	0.50	4202.70	0.70
17809	1.62	4204.62	7.9	8.9	0.99	439	1.00	4.50	4204.93	0.0083	82.0	0.043	0.137	0.50	4203.00	0.00
17950	1.98	4205.18	18.2	27.3	1.44	1723	1.00	1.46	4205.21	0.0005	223.0	0.193	0.084	0.30	4203.20	0.00

Section 17500
Reference Distance-360

X	Y	N	X	Y	N	X	Y	N
0.0	4205.9	0.030	5.0	4202.6	0.030	13.0	4204.8	
0.030								
2.0	4204.5	0.030	9.0	4202.5	0.030	16.0	4205.3	0.030
3.0	4202.9	0.030	11.0	4203.2	0.030	19.0	4206.6	0.030

Section 17600
Reference Distance-260

X	Y	N	X	Y	N	X	Y	N
0.0	4206.3	0..030	10.4	4202.6	0.030	26.0	4205.3	0.030
4.3	4204.9	0.030	15.6	4203.6	0.030			
5.2	4203.0	0.030	17.3	4204.7	0.030			

Section 17809
Reference Distance 82

X	Y	N	X	Y	N	X	Y	N
0.0	4205.4	0.030	4.0	4203.0	0.030	11.0	4206.2	0.030
2.0	4203.1	0.030	7.0	4203.6	0.030			

Section 17950
Reference Distance 223

X	Y	N	X	Y	N	X	Y	N
0.0	4207.9	0.030	10.0	4203.2	0.030	21.0	4204.1	0.030
7.0	4203.9	0.030	17.0	4203.2	0.020	25.0	4206.3	0.030

9.8 Tapered Inlets

General
9.8.1

A tapered inlet is a flared culvert inlet with an enlarged face section and a hydraulically efficient throat section. A tapered inlet may have a depression, or FALL, incorporated into the inlet structure or located upstream of the inlet. The depression is used to exert more head on the throat section for a given headwater elevation. Therefore, tapered inlets improve culvert performance by providing a more efficient control section (the throat). Tapered inlets with FALL also improve performance by increasing the head on the throat.

Tapered inlets are used in very specific applications. They have been used by MDT for retro-fitting steep culverts, where increased capacity is necessary, and it is expensive to excavate the roadway to replace the existing pipe. Construction difficulties are inherent for these structures, and a structural analysis is necessary. More information on their design is included in FHWA's HDS 5.

References

JM Norman, RJ Houghtalen, WJ Johnston, “Hydraulic Design of Highway Culverts,” HDS No. 5, FHWA-IP-85-15, FHWA, Washington, DC 20590, 1985

GK Young, JS Krolak, HYDRAIN - Integrated Drainage Design Computer System, Volumes 1-6, FHWA-RD-88-120, FHWA, 1987.

A Ginsberg, HY8 - Culvert Analysis Microcomputer Program, Applications Guide, FHWA-EPD-87-101 and software available from McTrans Center, 512 Weil Hall, University of Florida, Gainesville, Florida 32611.

“Guidelines for the Hydraulic Design of Culverts,” Task Force on Hydrology and Hydraulics, Subcommittee on Design, American Association of State Highway and Transportation Officials, 341 National Press Bldg., Washington, DC 20045, 1975.

GL Bodhaine, Measurement of Peak Discharge at Culverts by Indirect Methods, Techniques of Water-Resources Investigations of the USGS, Chapter A3, 1982.

G Reihsen and LJ Harrison, “Debris Control Structures,” HEC No. 9, Hydraulics Branch, Bridge Division, Office of Engineering, FHWA, Washington, DC 20590, August 1971.

SW Jens, “Design of Urban Highway Drainage - The State of the Art,”

FHWA-TS-79-225, Hydraulics Branch, Bridge Division, Office of Engineering, FHWA, Washington, DC 20590, August 1979

“Design of Small Canal Structures,” Bureau of Reclamation, Denver, Co., 1978.

“Culvert Design System,” FHWA-TS-80-245, Hydraulics Section, Wyoming Highway Department, Cheyenne, Wyoming 82001, December 1980.

“Design Charts For Open Channel Flow,” HDS No. 3, Hydraulics Branch, Bridge Division, Office of Engineering, FHWA, Washington, DC 20590, 1973.

JN Bradley, “Hydraulics of Bridge Waterways,” HDS No. 1, Second Edition, Hydraulics Branch, Bridge Division, Office of Engineering, FHWA, Washington, DC 20590, September 1973.

JO Shearman, WH Kirby, VR Schneider, and HN Flippo, “Bridge Waterways Analysis Model,” FHWA-RD-86-108, FHWA, Washington, DC.

HW King and EF Brater, “Handbook of Hydraulics,” Sixth Edition, McGraw-Hill Book Co., 1976.

“Analysis of Runoff from Small Drainage Basins in Wyoming,” USGS Water Supply Paper 2056, 1978.

Appendix A – High Velocity Culverts

Introduction
A.1

Appendix A of the Model AASHTO Drainage Manual is a 25 page discussion on High Velocity Culverts. MDT has not previously used this design. A high velocity culvert does not appear to have much application for MDT projects, and does not appear to be practical to build. This short section has been included only as a reference source.

Appendix B – Siphons

General
B.1

Low roadway grades at an irrigation crossing will often times make it impossible to provide the required cover over the irrigation pipe. When this happens it is necessary to use an inverted siphon. A conventional culvert crossing should always be designed and the cover checked to be sure a siphon is required. Because of the additional cost and maintenance associated with siphons, they should be used only when necessary.

The siphon details shown in Figures B-1 and B-2 should generally be used. Figure B-1 shows concrete transition structures at the inlet and outlet, a maximum slope of 2:1 on the pipe connected to the transitions, and a minimum slope of 0.5% on the pipe under the roadway. MDT has standard details for the concrete transitions and for the trash racks that can be attached to these transitions. This siphon should be used where available head is limited. Figure B-2 shows no transition structures at the inlet and outlet, and the same slope limitations. This siphon can be used where the head losses are not critical, and the ditch is small, so no transition is necessary.

The barrel of the siphon can be constructed out of either round corrugated steel pipe or round reinforced concrete pipe. Concrete pipe, because of its much more favorable roughness coefficient, is normally used. A corrugated steel barrel should be used only when the soil is reactive to concrete, when the ditch company requests it, or when the amount of head loss is not critical.

All of the joints in the siphon should be water tight. Siphon pipe is a separate bid item, not to be included with drainage pipe or irrigation pipe. If the head of a siphon exceeds twenty (20) feet, pipe and joint options other than CSP or standard RCP should be used.

Trash racks should be considered on all siphon installations. There are two possible reasons why trash racks might be required:

- **Because of their shape, siphons are extremely susceptible to plugging by floating debris. If any floating debris is expected, a trash rack should be placed on the inlet structure.**
- **Siphons are quite dangerous to children. If there is a chance that children will be near the canal or siphon, then trash racks should be placed on both the inlet and outlet structure for safety purposes.**

The basis for design of siphons is described in the USBR Design of Small Canal Structures. The procedure in this publication may be used for design. As an alternative, MDT's Standard Step Program can be used to determine the hydraulic characteristics of an existing or proposed siphon. In general, the maximum allowable backwater for a siphon is 0.3 foot. In either case, inlet control of the siphon should be checked.

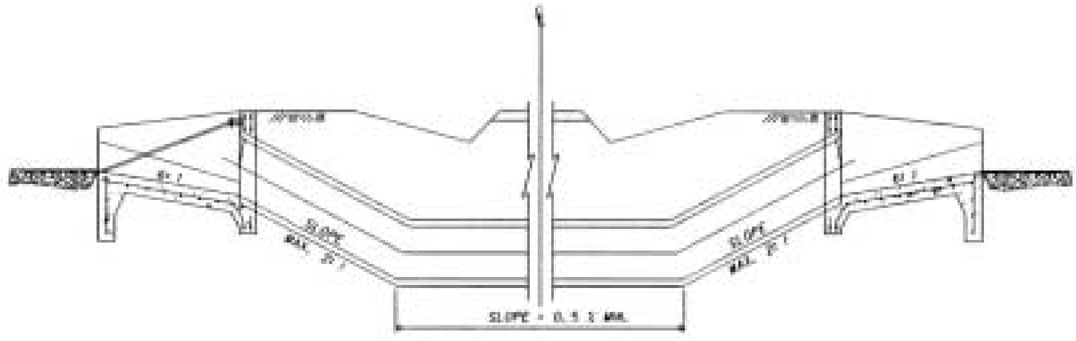


FIGURE B-1

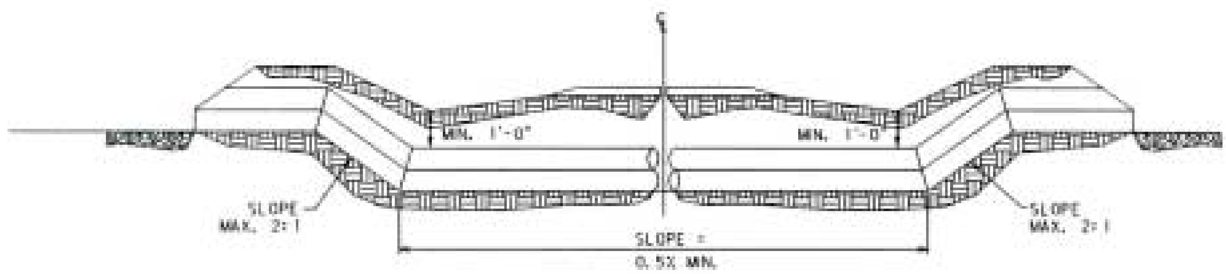


FIGURE B-2

Appendix C – Sediment Deposition in Culverts

Introduction
C.1

Appendix C of the Model AASHTO Drainage Manual is a 23 page discussion on Sediment Deposition in Culverts. MDT does not generally use a detailed design procedure to analyze sediment deposition. Locations where sediment is a concern can generally be analyzed using the maximum permissible velocity criteria in "Open-Channel Hydraulics", by Ven Te Chow. Locations where there are known sedimentation problems and there is a high risk may require a more detailed analysis, therefore this short section has been included to identify the Model AASHTO Drainage Manual as a reference source.

Recommended Manning's n Values

The following values of Manning's n are recommended for use on MDT projects.

Concrete Pipe	**0.012**
Concrete Boxes	**0.012**
Metal Pipe	
2 2/3 by 2 inch corrugations (up to 48" diameter)	**0.024**
3 by 1 inch corrugations (54" to 120" diameter)	**0.027-0.028**
5 by 1 inch corrugations (54" to 120" diameter)	**0.025-0.026**
6 by 2 inch corrugations (structural plate)	**0.033-0.035**

Note 1: **The Manning's n value for metal pipe with 3 x 1, 5 x 1, and 6 x 2 inch corrugations varies within the range shown depending on pipe size.** For further information concerning Manning's n values for selected conduits, consult Hydraulic Design of Highway Culverts, Federal Highway Administration, HDS No. 5.

Note 2: The values indicated in this table are recommended Manning's "n" values. Actual field values for older existing pipelines may vary depending on the effects of abrasion, corrosion, deflection and joint conditions. Concrete pipe with poor joints and deteriorated walls may have "n" values of 0.014 to 0.018. Corrugated metal pipe with joint and wall problems may also have higher "n" values, and in addition, may experience shape changes which could adversely affect the general hydraulic characteristics of the culvert.

Computation Form D.1

The computation form referenced in the Design Procedure Section is shown on the next page.

			Existing Structure				Selected Structure			
Station	Design Flow, cfs	100-year Flow, cfs	Size/ Type	O.T. Flow/ Elevation	O.T. Location	Historical Adequacy	Size/ Type	O.T. Flow/ Elevation	O.T. Location	Headwater Elevation

Appendix E – Culvert Service Life Guidelines

Design Service Life E.1

The design service life for new or replacement culverts will be:

- **40 years for field approach pipes**
- **75 years for mainline and major approach (county roads, etc.) pipes**
- **75 years for storm drains**

The design service life for overlay and minor widening projects will be:

- **20 years for all in place culverts**

The design service life for reconstruction (on existing alignment) and major widening projects will be:

- **In place culverts must have a remaining service life of 25 to 50 years. Where fill heights over 15 feet, ADTs over 5000, 4-lane highways, grade raises of over 5 feet or extension over 50% of in place length are involved, use 50 years. Culvert service life should be addressed during the scoping review.**

Metal Culverts E.2

1. Approach Pipe and Mainline Pipe

- **Adopt the modified AISI chart for estimating the average service life of steel pipe.**
- **Where the pH of the environment is greater than or equal to 7.3, use the following equation:**

$$\text{Years} = 2.94\, R^{0.41}$$

where R = minimum resistivity.

- **Where the pH of the environment is less than 7.3, use the following equation:**

$$\text{Years} = 27.58\, [\text{Log}_{10}R - \text{Log}_{10}(2160 - 2490 * \text{Log}_{10}\text{pH})]$$

where R = minimum resistivity and
pH = soil pH or water pH

- **Multiply the years of life by the appropriate factor from the table below for the various metal gages.**

Thickness - in.	0.064	0.079	0.109	0.138	0.168
Gage	16	14	12	10	8
Galvanized	1.0	1.3	1.6	2.2	2.8
Type II Aluminized	1.5	1.8	2.1	2.7	3.3
Aluminum	2.6	2.9	3.5	4.1	4.7

Corrosive soil limitations are shown in Figure E-1.

Soil pH	Resistivity	Steel	Type II Aluminized Steel	Aluminum	Concrete
pH > 8.5	R > 1000	Note 1	Note 5	No	Note 3
	800 < R < 1000	Note 1	No	No	Note 3
	500 < R < 800	No	No	No	Note 3
	R < 500	No	No	No	Note 3
6 < pH < 8.5	R > 2200	OK	OK	OK	Note 3
	1000 < R < 2200	Note 1	OK	OK	Note 3
	800 < R < 1000	Note 1	No	OK	Note 3
	500 < R < 800	No	No	No	Note 3
	R < 500	No	No	No	Note 3
5 < pH < 6	R > 1000	Note 1	OK	OK	Note 4
	800 < R < 1000	Note 1	No	OK	Note 4
	500 < R < 800	No	No	No	Note 4
	R < 500	No	No	No	Note 4
3 < pH < 5	All	No	No	No	Note 4
pH < 3	R > 300	No	No	No	Note 4
	R < 300	No	No	No	No

Notes:

1. **Use an approved bituminous or polymeric coating.**
2. **Where marble pH is higher than pH by 0.2 or more, steel pipe shall have an approved bituminous or polymeric coating.**
3. **Where sulfate content is between 0.25% and 1.0%, use Type 5 cement. Where sulfate content is greater than 1.0%, use Type 5 cement and either an approved bituminous coating or "C Wall" pipe.**
4. **Use Type 5 cement and either an approved bituminous coating or "C Wall" pipe.**
5. **Use an approved bituminous coating. No gage reduction allowed for the difference between Type II aluminized steel and galvanized steel.**

Figure E-1

Metal Culverts (continued)

2. **Siphons, Irrigation and active stream flow pipes**
   - **The life of these pipes is the time it takes for the first perforation to occur. Pipe perforation can cause bedding and backfill foundation deterioration. The AISI chart determines total life, and time to first perforation is estimated to be one-half the total life. Therefore, the life determined by use of the AISI chart (or the equations) must be divided by two to determine time to first perforation. Corrosiveness of the water should also be determined for these installations.**
3. **Fiber Bonded Pipe**
   - **Fiber bonded CSP is no longer commercially available and should not be specified.**
4. **Approved Pipe Coating**
   - **Bituminous and polymeric pipe coatings will protect the pipe for an additional 12 to 15 years. Use Figure E-1 to determine need for coating for main line crossings and major road approach pipes. For other approaches, coating will not be required if the Resistivity is greater than 800, but coating may be allowed to achieve the required 40 years of life. For approach pipes in soils with Resistivity less than 800, use the options noted in Figure E-1.**
5. **Thickness Limitations**
   - **Steel and aluminum pipes are not available in all sizes and thicknesses. The table below indicates the range of thicknesses generally specified by MDT.**

Size	Minimum Thickness	Maximum Thickness
18” CSP	0.064”	0.079”
24” - 30” CSP	0.064”	0.109”
36” CSP	0.064”	0.138”
42” - 78” CSP	0.064”	0.168”
84” - 90” CSP	0.079”	0.168”
96” - 108” CSP	0.109”	0.168”
114” - 120” CSP	0.138”	0.168”
18” CAP	0.060”	0.075”
24” CAP	0.060”	0.105”
30” CAP	0.075”	0.105”
36” CAP	0.075”	0.135”
42” CAP	0.060”	0.135”
48” - 54” CAP	0.060”	0.164”
60” - 72” CAP	0.075”	0.164”

Metal Culverts continued)

6. **Coating options are not available for all steel pipe thicknesses. The limitations are as follows:**
   - **Polymeric coating is available on pipe thicknesses from 0.064” to 0.138”.**
   - **Type II aluminized steel is available on pipe thickness from 0.064” to 0.138”.**

Concrete Pipe E.3

1. **Recommend Class “B” wall RCP when the soil pH is above 6 and the soluble sulfates (SO_4) are below 0.25%. When the sulfates are between 0.25% and 1.0% use Type 5 cement.**
2. **Use Class “C” wall RCP as an alternate for Class “B” wall bituminous coated concrete.**
3. **Use Class “C” wall RCP (Type 5 cement) when corrosive soils contain high sulfates (>1.0%) or when acid soils have a pH less than 6.0.**

Plastic Pipe E.4

Use High Density Polyethylene (HDPE) corrugated pipe for approach pipes only, in sizes 18” to 36”, meeting AASHTO M 294 (Type S).

Non-Corrosive Backfill E.5

Where extremely “hot” corrosive soils (Resistivity < 500) are encountered, non-corrosive passive backfill can be placed around the pipe. The backfill should extend at least five feet from the pipe, and be encased in a geomembrane to prevent contamination of the backfill. When non-corrosive backfill is used, and encased in a geomembrane, the resistivity of the backfill around the pipe can be used for culvert service life design. This is an expensive option, and the use of concrete (pipes or boxes) should be examined as a potentially less costly option.

Abrasion E.6

An estimate of the potential for abrasion is required at each pipe location in order to determine the need for invert protection. Abrasion potential should be estimated based on velocity in the pipe during the 2 year flood. Where velocity is less than 5 feet per second, the abrasion potential is low, and no special considerations are warranted. Where the velocity is greater than 5 feet per second and there is a coarse gravel bed material, there is some potential for abrasion, and the following remedial measures for metal pipes should be considered:

- **Increase the thickness of the pipe by one standard thickness; or**
- **Provide invert protection, consisting of invert paving or concrete lining.**

Protective coatings are not suitable for corrosion protection in abrasive locations.

Guideline Changes E.7

Some of the guidelines in this section represent changes from the June 1991 MDT Culvert Service Life Guidelines. Elimination of Type II Aluminized Steel in soils with resistivities less than 1000 was based on FHWA design guidelines. Aluminum pipe in soils with resistivities less than 800 requires coating, and there are concerns about the bituminous coating adhering to the aluminum pipe, so it was deleted. The June 1991 guidelines indicated that fiber-bonded steel pipe should be used in extremely corrosive soils (R less than 800). This has generally not been done at MDT, but will be encouraged with this revision. MDT has documented numerous cases of steel pipe perforation in short time periods in soils with resistivities less than 500, therefore this was a reasonable lower resistivity limit for steel pipes. Approach pipes have not typically been coated. This revision allows coating for approach pipes when necessary to achieve the required life, and limits use of steel pipe for approach to resistivities greater than 800 (unless it is fiber bonded). The use of High Density Polyethylene (HDPE) was included for approach pipes in sizes 18" to 36". A discussion on abrasion considerations was added.

A February 2000 revision eliminated the use of fiber bonded CSP since it is no longer commercially available.

PROCEDURE MEMORANDUM NO. 6 **Date: November 9, 1983**
IRRIGATION **Updated: March 1996**

GENERAL

Irrigation involvement requiring the design of replacement facilities is divided into two categories - minor and major. Minor irrigation includes facilities required for small irrigation ditches and which generally serve only one landowner. These facilities include highway crossing structures, channel changes, and control structures. Major irrigation includes the facilities required for large canals or distribution laterals which are part of an irrigation project and which is under the jurisdiction (administrative or supervisory) of an agency of the federal or state government or an irrigation district. The facilities involved are the same as those for minor irrigation; however, approval of the proposed replacement facilities from the owner(s) is necessary.

LOCATION HYDRAULIC STUDY REPORTS (LHSR)

Potential involvements with minor irrigation facilities need not be discussed in the LHSR. However, where the involvement is so extensive that it will constitute a significant part of the project, then a discussion of the involvement should be included.

Potential involvements with major irrigation facilities shall be discussed in the LHSR. Provide to the "Lead Agency" a summary of potential involvements with any major irrigation facilities and identify the owner.

DESIGN STUDIES AND REPORTS

A. Minor Irrigation

Substantial portions of the minor irrigation design can be performed by the road designer. The hydraulic designer will coordinate with the road designer throughout project development on these items and provide technical assistance, check designs or perform designs as is determined appropriate for individual situations.

B. Major Irrigation

Substantial delays in project development, through R/W acquisition, can occur when the design and coordination of major irrigation facilities are not completed in a timely manner. Adherence to the general procedure outlined below in addition to assuring that design tasks or activities are completed in accordance with the Preconstruction Management System flow chart will minimize potential problems.

1. **Maintain close coordination with the road designer to keep informed of the status of road plan and R/W plan development, and attempt to insure each irrigation facility is identified as a parcel on the Right-of-Way plans.**
2. **Initiate early coordination with the owner or operator of the system to determine design requirements. Also request information on modifications or betterments to their system that they may be considering, may desire us to incorporate into our project, and would be able to participate in financing where determined necessary.**
3. **Document all reviews, meetings and recommendations made. Documentation should generally include design flow, area irrigated, starting water surface elevation or slope used, and backwater created by the new culvert.**

Appendix G – Flood Routing Culvert Design

Introduction
G.1

Flood routing through a culvert is a practice that evaluates the effect of temporary upstream ponding caused by the culvert's backwater. A flood routing analysis may also show that what was thought to be an inadequate existing culvert is, in fact, adequate. Often existing culverts require replacement due to corrosion or abrasion. A less costly alternative is to place a smaller culvert inside the existing culvert. A flood routing analysis may, where there is sufficient storage, demonstrate that this is acceptable provided that no increase in flood hazard results.

Hydrology
G.2

The hydrology necessary for a flood routing includes an instantaneous peak flow and a hydrograph. The instantaneous peak flow should be determined using the methods described in Chapter 7, Hydrology. The hydrograph should be developed using either the Wyoming Unit Hydrograph, the SCS Synthetic Unit Hydrograph, or the Montana Unit Hydrograph, as referenced in Chapter 7. MDT's Flood Routing Program can be used for the computations of the first two methods. When using the Montana Unit Hydrograph, the computations must be done separately, and the resulting hydrograph input into MDT's Flood Routing Program.

The USGS collected rainfall and associated runoff data at five gaging stations between 1992 and 1995. This data was analyzed by Aaron Eschler in an attempt to compare it to the Wyoming Hydrograph Method. Using the peak flow and the runoff volume determined from the continuous gage, the shape of the hydrograph matched the actual hydrographs very closely. The problem in using this information at other sites is that while there are good techniques for estimating the peak flow, MDT does not have good techniques available to estimate the runoff volume. Using the 18 runoff events recorded at the five gages, a relationship between peak flow and runoff volume was established. The relationship is

$$Vol = 0.708 * Q^{0.784}$$

where Vol is in acre-feet, and
Q is in cfs.

The correlation coefficient for the equation is 0.855, with a standard error of 56%. This relationship, along with the procedure described in the Wyoming report (USGS Water Supply Paper 2056), can be used to develop an inflow hydrograph for routing purposes. In order to use the routing program in MDT's Hydraulics programs, it is necessary to convert the acre-feet of runoff into inches of runoff. This can be done by multiplying by 12 (to get acre-inches) and dividing by the drainage area in acres (to get inches). This method is recommended for use in the plains areas of the eastern half of the state. The five gages that were used in the analysis were:

06154510	**Kuhr Coulee Trib. near Dodson (Phillips County)**
06327450	**Cains Coulee at Glendive (Dawson County)**
06164623	**Little Warm Creek Trib. near Lodgepole (Phillips County)**
06129700	**Gorman Coulee near Cat Creek (Petroleum County)**
06217700	**North Fork Crooked Creek Trib. near Shepherd (Yellowstone County)**

Routing G.3

After the input hydrograph has been determined, it is necessary to determine the stage-storage relationship of the temporary upstream pond. This can generally be done using detailed contour maps of the area.

The next step is to develop a stage-discharge relationship of the proposed pipe. This is done using one of the approved methods of culvert analysis in this chapter.

The stage-storage and stage-discharge relationships are then input into MDT's Flood Routing Program, along with the hydrograph. The program then computes the routing, with output consisting of an outflow hydrograph, the volume stored and the maximum stage.

PROCEDURE MEMORANDUM NO. 9 **Date: November 9, 1983**
HYDRAULIC DATA ON PLANS **Updated: March 1996**

GENERAL

The Federal Aid Policy Guide (FAPG) 23 CFR 650A has established design requirements as well as requirements for showing hydraulic data on the plans for federal-aid highway projects. For MDT projects, this will be accomplished with a separate plan sheet, HYDRAULIC DATA SUMMARY SHEET, which will contain the required data for all appropriate culverts, bridges, and longitudinal encroachments and will be prepared by the Hydraulics designer. This sheet has been developed to provide a uniform system for showing the data required by Section 650.117 for encroachment locations.

APPLICABILITY

A. Bridges

1. **Data will generally not be required for bridge crossings involving minor widening.**
2. **Data will be shown for all bridge crossings involving the construction of a new bridge.**

B. Culverts

1. **Lengthening of in-place drainage culverts.**
   a. **Data will generally not be required for culvert installations involving lengthening due to slope flattening or minor widening. Where information from Maintenance or other documentation indicates that the existing culvert does not meet design standards (e.g., due to frequent overtopping), the data should be shown.**
   b. **Data will be shown for culvert installations where the lengthening of an existing culvert is necessary due to a modification in the road grade which increases the overtopping elevation.**
2. **New drainage culverts.**
   a. **Data will be required for all new culvert installations, except as noted in item (b) below, for culverts larger than 24 inch in diameter and equivalent arches.**
   b. **Modified data may be shown for small rural drainage crossings where the culvert selected is 36 inches in diameter or smaller. Additional guidance for these situations is provided in Procedure Memorandum No. 10.**

C. Longitudinal Encroachments

1. **Data will generally not be required for longitudinal encroachments on projects which involve minor widening. Where information from Maintenance or other documentation indicates that the existing roadway does not meet design standards (e.g., due to frequent overtopping), or the encroachment is considered to be significant, the data should be shown.**
2. **Data will be shown for all longitudinal encroachments upon the base floodplain on all reconstruction and original construction projects.**

EXCEPTIONS

In addition to those cases previously listed, Hydraulic data will be shown for all encroachments upon floodplains which have been delineated by a detailed study or for which early coordination with floodplain officials indicates that a permit will be required.

DOCUMENTATION

The project design file shall contain the studies required by the FAPG as well as documentation of all exceptions.

PROCEDURE MEMORANDUM NO. 10 **Date: November 16, 1983**
EXCEPTION – HYDRAULIC DATA ON PLANS **Updated: March 1996**

GENERAL

This memorandum provides guidance for using the exception granted in paragraph B(2)(b) of PM 9. This procedure applies only to small rural drainages where preliminary hydrologic/-hydraulic analysis does not agree with historical performance of existing drainage facilities and for which the culvert recommended is 36 inches in diameter or smaller.

PROCEDURE

For these crossings, an economic/risk assessment documenting that the culvert selected is appropriate will suffice. The assessments may be very short relying heavily on sound hydraulic engineering judgment, but including three major elements. These are 1) a hydrologic analysis using the current USGS prediction equations, 2) culvert sizing calculations based upon peak flow, and 3) an indication that the potential for damages is minimal or nonexistent. The remainder of the assessment may include considerations similar to the following examples:

1. **The peak flow analysis indicates that a 60 inch RCP is necessary. However, the existing culvert or culverts at crossings of comparably sized drainages in the immediate vicinity are 30 or 36 inch RCPs and have been adequate. Floodwater storage is probably a factor, but survey data is inadequate to allow a routing design and additional survey would be unwarranted. High headwater would result in minimal damage, so specify a 30 or 36 inch RCP.**
2. **Peak flow analysis indicates that a 30" RCP should be adequate. However, field drainage recommendation, historic performance of the existing structure or similar sized structure on comparably sized drainages in the immediate vicinity, or erosion evidence indicates that a larger pipe is probably warranted. A larger culvert, up to a 36-inch, can be recommended.**

OPTIONAL PIPE RECOMMENDATIONS

For drainage recommendations based on this procedure analysis for optional materials will not be necessary. The following table may be used for determining optional sizes:

RCP or RCPA	CMP or CMPA
24" or 28" x 18"	30" or 35" x 24"
30" or 36" x 22"	36" or 42" x 29"
36" or 44" x 27"	42" or 49" x 33"

HYDRAULIC DATA

The hydraulic data shown on the Hydraulic Data Summary Sheet for culverts recommended under this procedure shall be limited to only design flow. High water elevations and overtopping flood information is not required. Design floods for this procedure shall be in accordance with Appendix A of the Hydrology Chapter.

Appendix I – Culvert Outlet Riprap Apron

The procedure outlined here is intended to serve as a guide.

During field reviews, note the observed scour, describe the scoured material and give approximate dimensions of the scour hole. Compare the existing (observed) scour hole with the design procedure below and use engineering judgment to temper the size of the apron.

If the outlet velocity at the 10-year flow is above 10 feet per second or the observed scour warrants protection, design a horizontal riprap outlet apron.

Empirical Horizontal Riprap Blanket Equations (From Report No. FHWA-RD-75.508, Culvert Outlet Protection, by M.G. Schilling):

$$D_{50} = (0.02 * (D_o)^2/TW) * (Q/D_o^{2.5})^{1.333}$$

$$C = [1.7 * (D_o) * (Q/D_o^{2.5})] + 8$$

$$A = 3 * D_o$$

$$B = A + C$$

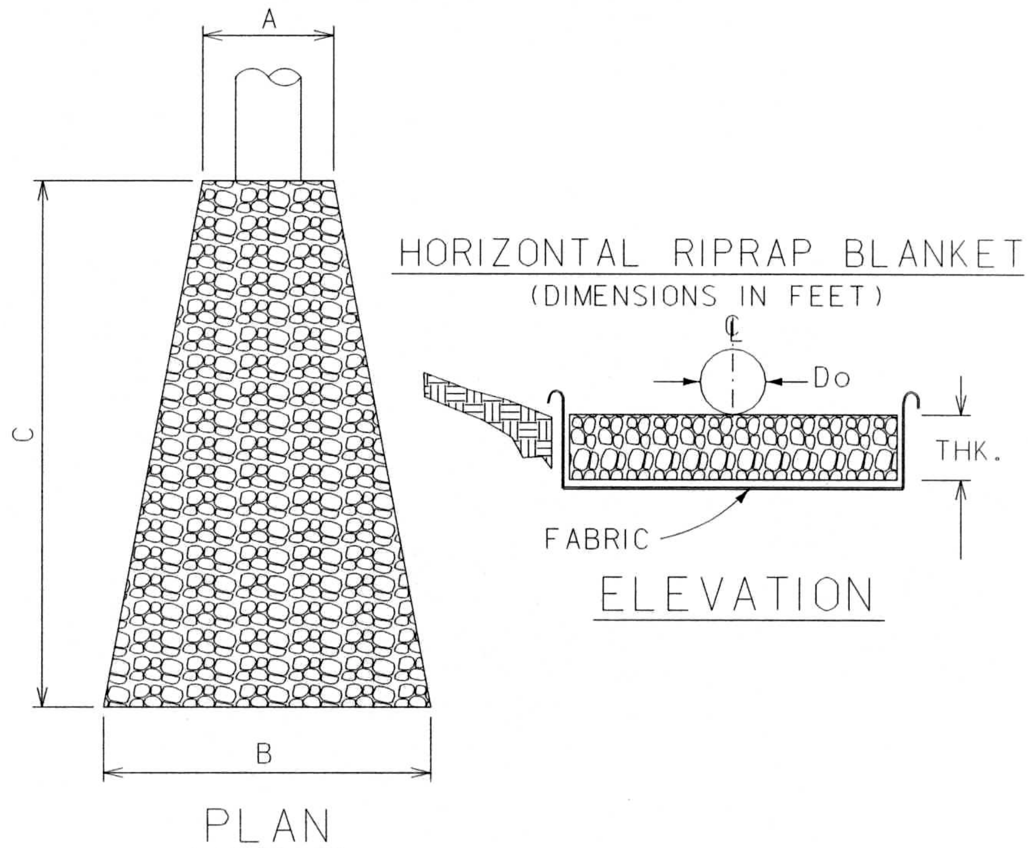
Where

D_{50}	**= Median Stone Diameter (ft)**
C	**= Basin Length (ft)**
A	**= Basin Inlet Width (ft)**
B	**= Basin Outlet Width (ft)**
D_o	**= Pipe Diameter (or Rise)**
TW	**= Tailwater, $D_o/2$**

The blanket thickness will be twice the D_{50}. MDT standard riprap sizes (Class I, Class II and Class III) should be used. Class I D_{50} = 0.66 ft, Class II D_{50} = 1.32 ft, Class III D_{50} = 2.00 ft.

For pipe sizes up to 72 inches, reduce C by not using 1.7 factor and make B = (C/3) + A.

On March 21, 1996, the Federal Highway Administration released a new version of Chapter V "Estimating Scour at Culvert Outlets," of Hydraulic Engineering Circular No. 14. The new chapter contains substantially revised scour estimation equations which have been generalized by culvert shape, slope and drop height. These equations may be used for computing the size of scour holes for unprotected outlets. They can be used for comparison to the results of the equations above.



STATION	A	B	C	THK.	RIPRAP CLASS

Appendix J – Encasement Pipe Material Guidelines

Purpose

The following is intended to serve as a general guideline for material selection when Hydraulics is asked to specify an encasement pipe for pressure irrigation lines, sanitary sewers, water lines, etc. This request generally comes in the form of a landowner request or possibly at the request of a municipality for a future water or sanitary sewer line.

Encasement pipes may be required for the following reasons.

- **To prevent damage to structures caused by soil erosion or settlement in case of pipe failure or leakage.**
- **To permit economical pipe removal and placement in the future.**
- **To accommodate regulations or requirements imposed by public or private owners of property in which the pipe is installed.**
- **To permit boring rather than excavation where open excavation would be impossible or prohibitively expensive.**

Guidelines

I. In general, MDT prefers to provide uncased pipeline crossings through the roadway. In these circumstances the following materials can be considered for pipeline crossings (pressure irrigation, water line) without an encasement.

- **PVC Pressure Water Pipe: Standard Specification 708.07**
- **Ductile Iron Water Pipe: Standard Specification 709.01.1**
- **Steel Water Pipe: Standard Specification 709.01.2**

II. When installation of an encasement pipe is warranted the following materials can be considered. Please note the specific applications for each material. Current MDT service life guidelines will also apply.

CORRUGATED STEEL PIPE (CSP)

- **Generally used for larger insert applications**
- **Sizes 36”-120”**
- **Fill Heights (see Road Design Manual)**
- **Standard bedding and backfill per MDT specifications**
- **Evaluate soil resistivity and pH to determine life expectancy**

PVC GRAVITY SEWER AND DRAIN PIPE (SDR 35)

- **Specified in sizes 4”-12” per Section 708.05 of the Standard Specifications**
- **Fill heights are generally acceptable in the 3’-10’ range**
- **Provide good bedding and backfill requirements (see Montana Public Works Standard Specifications; Standard Drawing No. 02221-1)**
- **Excellent corrosion resistance/ Can be used in most environments**
- **Smooth interior provides ease of installation for pipe insert**

*** HIGH DENSITY POLYETHYLENE (HDPE)**

- **Specified in sizes 12”-36” per Section 708.07 of the Standard Specifications (AASHTO M 294; Type S)**
- **Fill heights are generally acceptable in the 2’-10’ range**
- **Provide good bedding and backfill requirements (see Montana Public Works Standard Specifications or manufacturer’s recommendations)**
- **Excellent corrosion resistance/ Can be used in most environments**
- **Smooth interior provides ease of installation for pipe insert**

*** Subject to review and approval of the Hydraulic Engineer**

SMOOTH STEEL

- **Specified in sizes 4”-96”. See AWWA No. M11 Steel Pipe Design and Installation manual**
- **See table below regarding allowable fill heights (reference AWWA No. M11)**
- **Provide good bedding and backfill requirements in embankment situation per Montana Public Works Standard Specifications**
- **Smooth interior allows for ease of installation for pipe insert**
- **Can be bored and jacked**
- **Good application when grade control required (e.g., sanitary sewer insert)**

Smooth Steel Pipe, Allowable Fill Heights

Pipe Size	Minimum Cover	0.25”	0.375”	0.50”	0.625”	0.75”
12”	2’	50’	100’	-	-	-
18”	2’	10’	35’	80’	100’	-
24”	2’	-	18’	40’	70’	100’
36”	2’	-	-	12’	20’	40’
48”	2’	-	-	-	10’	17’
60”	2’	-	-	-	-	9’

REINFORCED CONCRETE PIPE (RCP)

- **Specified in sizes 12”-84”**
- **Fill heights (see Road Design Manual)**
- **Standard MDT bedding and backfill requirements**
- **Smooth interior allows for ease of installation for pipe insert**
- **Can be bored and jacked**

SPECIAL CONSIDERATIONS/INFORMATION

1. **Cost**
2. **As the insert becomes larger the requirement for a smooth interior encasement becomes more important**
3. **Skid systems should be utilized for insert**
4. **See the following table for casing sizes required if inserting PVC in an encasement (AWWA No. M23)**

Table of Casing Sizes

Pipe Size (insert) (diameter)	Casing Size (diameter)
4”	8”–10”
6”	10”–12”
8”	14”–16”
10”	16”–18”
12”	18”–20”

FURTHER REFERENCES:

1. **Steel Pipe Design and Installation, AWWA No. M11**
2. **A Guide for Accommodating Utilities Within Highway Right-of-Way, AASHTO**
3. **PVC Pipe-Design and Installation, AWWA No. M23**
4. **Accommodation of Utility Plant within the Rights of Way of Urban Streets and Highways, State of the Art and Manual of Improved Practice; (FHWA RD-75-8 and 75-9)**
5. **MDT Utilities Manual**